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UGANDA ADVANCED CERTIFICATE OF EDUCATION (UACE)
END OF FIRST TERM EXAMINATIONS 2026
S.6 P510/1 PHYSICS (Paper 1)

MARKING SCHEME & DETAILED SOLUTIONS

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Total Marks: 80 marks (20 marks per section × 4 sections)

KEY TO MARKING SCHEME
✓ Correct final answer (full marks for that step)
[M] Method mark — awarded even if arithmetic error follows
[A] Accuracy mark — depends on correct method
[B] Independent mark for statement/definition
∴ Shaded blue rows indicate final answer lines

SECTION A: PARTICLES — MARKING SCHEME

ITEM 1 — Suggested Solutions

Total: 20 marks

(a) Half-life, decay constant from count rate data. **[05]**

Plot corrected count rate (y-axis) vs time in hours (x-axis). Points: (0, 640), (2, 452), (4, 320), (6, 226), (8, 160). **[B1]**

Graph is a smooth exponential decay curve through all plotted points. Axes labelled with units. **[B1]**

From graph: count rate halves from 640 → 320 between t = 0 and t = 4 h → $t_{½}$ = 4.0 hours **[M1]**

∴ Half-life $t_{½}$ = 4.0 hours = 4.0 × 3600 = 14 400 s ✓

$\lambda = \ln 2 / t_{½}$ = 0.6931 / 14 400 **[M1]**

∴ $\lambda = 4.81 \times 10^{-5}\ s^{-1}$ ✓

(b) Decay equations for Uranium-238 chain and identification of final nuclide. **[05]**

Alpha decay of U-238:

∴ ${}^{238}_{92}U \rightarrow {}^{234}_{90}Th + {}^{4}_{2}He$ ✓

📌 **Note:** *Mass number: 238 − 4 = 234; Proton number: 92 − 2 = 90 → Thorium-234.*

First β^- decay of Th-234:

∴ ${}^{234}_{90}Th \rightarrow {}^{234}_{91}Pa + {}^{0}_{-1}e + \bar{\nu}_e$ ✓

Second β^- decay of Pa-234:

∴ ${}^{234}_{91}Pa \rightarrow {}^{234}_{92}U + {}^{0}_{-1}e + \bar{\nu}_e$ ✓

∴ Final nuclide: Uranium-234, symbol ${}^{234}U$, proton number 92, mass number 234 ✓

(c) Binding energy per nucleon of He-4 and explanation using B.E. curve. **[06]**

Mass of 2 protons + 2 neutrons = 2(1.00728) + 2(1.00867) = 2.01456 + 2.01734 = 4.03190 u **[M1]**

Mass defect Δm = 4.03190 − 4.00150 = 0.03040 u **[A1]**

Binding energy BE = Δm × 931.5 = 0.03040 × 931.5 = 28.32 MeV **[M1]**

∴ Binding energy per nucleon = 28.32 / 4 = 7.08 MeV/nucleon ✓

Explanation (B.E. curve):

- Nuclei in the middle of the periodic table (iron region, A ≈ 56) have the HIGHEST binding energy per nucleon (~8.8 MeV).
- Nuclear FISSION: a very heavy nucleus (low B.E./nucleon) splits into smaller fragments that have higher B.E./nucleon → products are more stable → energy is released equal to the gain in binding energy.

∴ Nuclear FUSION: very light nuclei (low B.E./nucleon, e.g. H isotopes) combine to form a heavier nucleus (higher B.E./nucleon) → products more tightly bound → energy released as the difference in binding energies. ✓

(d) TWO applications of nuclear radiation with risks and management. **[04]**

- Application 1 — Medical Radiotherapy (as at UCI): radioactive sources emit gamma/beta radiation to target and destroy cancerous tumour cells. **Risk:** radiation may damage healthy surrounding tissue. Management: precise beam focusing, lead shielding, fractionated dosing.

- Application 2 — Industrial Thickness Gauging: a radioactive source and detector measure how much radiation passes through a material to control its thickness in real time (e.g. paper, steel sheets). **Risk:** long-term exposure for workers. Management: sealed sources, remote handling, regular dosimetry monitoring, lead shielding.

📌 **Note:** *Award [1] per correctly named application + [1] per identified risk with management. Max [4].*

OR

ITEM 2 — Suggested Solutions — Total: 20 marks

(a) Photon energy of blue light in eV; assess retinal risk. **[04]**

$E = hc/\lambda = (6.63 \times 10^{-34} \times 3.0 \times 10^{8}) / (450 \times 10^{-9})$ **[M1]**

$E = 1.989 \times 10^{-25} / 4.50 \times 10^{-7} = 4.42 \times 10^{-19}$ J **[A1]**

∴ $E = 4.42 \times 10^{-19} / 1.6 \times 10^{-19} = 2.76$ eV ✓

Damage threshold = 3.1 eV; photon energy = 2.76 eV < 3.1 eV **[M1]**

∴ Since each photon carries only 2.76 eV — less than the 3.1 eV damage threshold — blue light from the monitors cannot cause permanent photochemical damage to the retina. Mr. Wasswa should reassure students that normal use poses no permanent retinal injury risk from photon energy alone. ✓

(b) State the photoelectric effect. **[01]**

∴ The photoelectric effect is the emission of electrons from the surface of a metal when electromagnetic radiation of sufficiently high frequency (at or above the threshold frequency) is incident on the metal surface. ✓

(c) Photoelectric investigation on sodium; KE_max and stopping potential. **[06]**

Work function $\varphi = 2.28$ eV; photon energy $E = 2.76$ eV

$E = 2.76$ eV $> \varphi = 2.28$ eV → photoelectric emission WILL occur. **[B1]**

$KE_{max} = E - \varphi = 2.76 - 2.28 = 0.48$ eV **[M1]**

∴ $KE_{max} = 0.48 \times 1.6 \times 10^{-19} = 7.68 \times 10^{-20}$ J ✓

Stopping potential: $eV_s = KE_{max} \rightarrow V_s = KE_{max}(eV) / e = 0.48 \text{ eV} / e$ **[M1]**

∴ Stopping potential $V_s = 0.48$ V ✓

(d) Wave theory failures to explain photoelectric observations. **[04]**

(i) Instantaneous emission:

- Wave theory predicts that energy from light arrives continuously and spread over the whole surface. A dim source should take time (seconds to hours) to deliver enough energy to free an electron. In reality, emission is instantaneous ($< 10^{-9}$ s) even with very dim light — proving energy arrives in discrete quanta (photons), not continuously.

(ii) Threshold frequency:

- Wave theory predicts that with a sufficiently intense wave, electrons should eventually be emitted at any frequency, since intensity determines energy delivered. In reality, no emission occurs below a fixed threshold frequency regardless of intensity — proving emission depends on individual photon energy ($E = hf$) exceeding the work function, not on wave intensity.

(d) Symptoms of blue light eye damage and protective measures. **[06]**

Symptoms (award [1] each, max [2]):

- Digital eye strain / asthenopia: tired, sore, irritated eyes after prolonged screen use due to reduced blink rate.
- Disrupted circadian rhythm / insomnia: blue light suppresses melatonin production, causing difficulty falling asleep — explaining students' sleep complaints.
- Photokeratitis: inflammation of the cornea from high-energy radiation exposure (similar to 'snow blindness').

Protective measures (award [1] each, max [4]):

- Install blue light filter screen protectors or enable Night Mode/blue light filter software on all monitors to reduce blue wavelength emission.
- Apply the 20-20-20 rule: every 20 minutes, look at an object 20 feet away for 20 seconds to relax the ciliary muscles and reduce eye strain.
- Limit evening lab sessions to reduce blue light exposure close to bedtime, protecting students' melatonin cycles and sleep quality.
- Provide anti-reflective, blue-light-blocking spectacles for students who spend the most time at screens.

SECTION B: FORCE AND MOTION — MARKING SCHEME

ITEM 3 — Suggested Solutions Total: 20 marks

(a) Reconstruct braking: deceleration, stopping distance, braking force. **[06]**

(i) Deceleration:

$a = (v - u) / t = (0 - 30) / 5.0 = -6 \text{ m s}^{-2}$ **[M1]**

∴ Deceleration = 6 m s^{-2} ✓

(ii) Stopping distance:

$s = ut + \frac{1}{2}at^2 = 30(5.0) + \frac{1}{2}(-6)(5.0)^2 = 150 - 75$ **[M1]**

∴ s = 75 m (skid mark length Constable Nabirye should measure) ✓

(iii) Braking force:

$F = ma = 1\,200 \times 6$ **[M1]**

∴ F = 7 200 N ✓

(b) Projectile motion: time of flight, range, impact velocity. **[07]**

(i) Time of flight — vertical motion ($u_y = 0$, h = 80 m):

$h = \frac{1}{2}gt^2 \rightarrow 80 = \frac{1}{2} \times 10 \times t^2 \rightarrow t^2 = 16$ **[M1]**

∴ t = 4.0 s ✓

(ii) Horizontal range:

$x = u_x \times t = 20 \times 4.0$ **[M1]**

∴ x = 80 m from the base of the building ✓

(iii) Impact velocity:

$v_x = 20 \text{ m s}^{-1}$ (unchanged, no air resistance)

$v_y = u_y + gt = 0 + 10 \times 4.0 = 40 \text{ m s}^{-1}$ (downward) **[M1]**

$v = \sqrt{(v^{x2} + v^{y2})} = \sqrt{(400 + 1600)} = \sqrt{2000}$ **[M1]**

∴ $v = 44.7 \text{ m s}^{-1}$ ✓

Direction: $\theta = \arctan(v_y / v_x) = \arctan(40/20) = \arctan(2) = 63.4°$ below horizontal **[A1]**

(c) Resistive forces on level road and incline. **[05]**

(i) Level road at constant speed — driving force = resistive force:

$P = Fv \rightarrow F = P/v = 60\,000 / 30$ **[M1]**

∴ Total resistive force = 2 000 N ✓

(ii) On incline ($\sin\theta = 0.05$):

Driving force available = P/v = 2 000 N (same) **[M1]**

Weight component down slope = $mg \sin\theta = 1\,200 \times 10 \times 0.05 = 600$ N **[M1]**

Net force = 0 (constant speed) $\rightarrow F_{drive} = F_{resistance} + mg \sin\theta$

∴ New resistive force = 2 000 − 600 = 1 400 N ✓

(d) Impulse-momentum theorem and vehicle safety features. **[02]**

Impulse = F × Δt = Δp = m(v − u). For a given change in momentum Δp:

- Crumple zones deform progressively during impact, increasing the collision time Δt. Since F = Δp/Δt, a longer collision time produces a smaller average force on the occupant → reduces risk of fatal injury.
- Air bags inflate instantly and cushion the occupant's head and chest, extending the stopping distance and time, again reducing the peak force transferred to the body during sudden deceleration.

OR

ITEM 4 — Suggested Solutions — Total: 20 marks

(a) Free-body diagram, wall reaction, minimum friction coefficient. **[08]**

Free-body diagram must show: R_w (horizontal, from smooth wall at top), R_g (vertical, from ground at base), F_f (horizontal friction at base, pointing toward wall), W_L = 250 N at midpoint, W_P = 750 N at ¾ L. **[B2]**

Taking moments about the base (eliminates ground reactions):

Clockwise moments = W_L × (L/2)cosθ + W_P × (3L/4)cosθ **[M1]**

= 250 × 4.0 × cos60° + 750 × 6.0 × cos60° = 250×4×0.5 + 750×6×0.5 = 500 + 2250 = 2750 N m **[A1]**

Anticlockwise moment = R_w × L × sinθ = R_w × 8.0 × sin60° = R_w × 8.0 × 0.8660 = 6.928 R_w **[M1]**

For equilibrium: 6.928 R_w = 2750

∴ R_w = 2750 / 6.928 = 397 N (horizontal reaction at wall) ✓

Vertical equilibrium: R_g = W_L + W_P = 250 + 750 = 1 000 N **[M1]**

Horizontal equilibrium: F_f = R_w = 397 N

μ_{min} = F_f / R_g = 397 / 1000 **[M1]**

∴ Minimum coefficient of static friction μ = 0.397 ≈ 0.40 ✓

(b) Satellite orbital speed, period, and gravitational potential energy. **[07]**

Orbital radius: r = R_E + h = $6.4×10^6 + 4.0×10^5$ = $6.80×10^6$ m

(i) Orbital speed — equate gravitational force to centripetal force:

GMm/r² = mv²/r → v = √(GM/r) **[M1]**

v = $\sqrt{(6.67×10^{-11} × 6.0×10^{24} / 6.80×10^6)}$ = $\sqrt{(5.885×10^7)}$ **[A1]**

∴ v = 7 672 m s^{-1} ≈ 7.67 km s^{-1} ✓

(ii) Orbital period:

T = 2πr / v = 2π × $6.80×10^6$ / 7 672 = 5 568 s **[M1]**

∴ T = 5 568 / 60 = 92.8 minutes ≈ 93 minutes ✓

(iii) Gravitational potential energy:

$GPE = -GMm / r = -(6.67\times10^{-11} \times 6.0\times10^{24} \times 500) / 6.80\times10^{6})$ **[M1]**

$= -2.001\times10^{17} / 6.80\times10^{6}$

∴ $GPE = -2.94 \times 10^{10}$ J ✓

(c) Archimedes' principle and floating steel barge. **[03]**

∴ Archimedes' principle: when a body is wholly or partially immersed in a fluid, it experiences an upthrust (buoyant force) equal in magnitude to the weight of fluid displaced. ✓

- A solid steel ball sinks because its weight (downward) exceeds the upthrust — the volume of water it displaces weighs less than the ball itself, since steel is denser than water.
- A steel barge is hollow with a large volume. Its shape displaces a volume of water whose weight equals or exceeds the total weight of the barge and its cargo. The average density of the barge (steel walls + enclosed air) is less than water, so upthrust ≥ weight → the barge floats.

(d) Terminal velocity definition and conditions. **[02]**

∴ Terminal velocity is the constant maximum velocity reached by a body falling through a viscous fluid, at which point the net force on the body is zero. ✓

- As the body accelerates downward, drag force (viscous resistance) increases with speed. When drag force + upthrust exactly equals the weight of the body, the net force becomes zero, acceleration ceases, and the body continues at constant (terminal) velocity.

SECTION C: ENERGY — MARKING SCHEME

ITEM 5 — Suggested Solutions

Total: 20 marks

(a) Third harmonic standing wave: sketch, wavelength, frequency, fundamental. **[07]**

(i) Third harmonic sketch: 3 loops between fixed ends. Nodes at both ends and at 2 interior points (L/3 and 2L/3). Antinodes at L/6, L/2, 5L/6. Award [B1] for correct pattern, [B1] for labelled nodes and antinodes. **[B2]**

(ii) Wavelength in 3rd harmonic: $L = 3\lambda/2 \rightarrow \lambda = 2L/3$ **[M1]**

$\therefore\ \lambda = 2 \times 0.80 / 3 = 0.533$ m ✓

(iii) Frequency: $f = v/\lambda = 120 / 0.533$ **[M1]**

$\therefore\ f_3 = 225$ Hz ✓

(iv) Fundamental: $f_1 = f_3 / 3 = 225 / 3$ **[M1]**

$\therefore\ f_1 = 75$ Hz ✓

(b) Doppler frequency for moving observer; ultrasound blood flow application. **[06]**

(i) The Doppler effect is the apparent change in frequency of a wave perceived by an observer due to relative motion between the source and the observer. **[B1]**

(ii) Observer moving toward stationary source:

$f' = f \times (v + v_o) / v = 850 \times (340 + 15) / 340 = 850 \times 355/340$ **[M1]**

$f' = 850 \times 1.0441$

$\therefore\ f' = 887.5 \text{ Hz} \approx 888$ Hz ✓

(iii) Medical ultrasound application:

- An ultrasound transducer emits a pulse of high-frequency sound (typically 2–15 MHz) toward a blood vessel. Red blood cells moving in the artery reflect the pulse back to the transducer.
- Because the cells are moving, the reflected frequency differs from the transmitted frequency — a Doppler shift Δf. The speed of blood flow v_{blood} is calculated from: $\Delta f = 2f_0 v_{blood} \cos\theta / c$, where θ is the angle between the ultrasound beam and blood flow direction.
- This allows non-invasive, real-time measurement of blood flow speed in arteries — used in echocardiography and vascular assessment.

(c) SHM: angular frequency, maximum speed, total energy. **[05]**

(i) Angular frequency:

$\omega = \sqrt{(k/m)} = \sqrt{(200 / 0.50)} = \sqrt{400}$ **[M1]**

$\therefore\ \omega = 20 \text{ rad s}^{-1}$ ✓

(ii) Maximum speed (at equilibrium position, all PE → KE):

$v_{max} = \omega A = 20 \times 0.10$ **[M1]**

$\therefore\ v_{max} = 2.0 \text{ m s}^{-1}$ ✓

(iii) Total mechanical energy:

$E = \frac{1}{2}kA^2 = \frac{1}{2} \times 200 \times (0.10)^2 = \frac{1}{2} \times 200 \times 0.01$ [M1]

$\therefore E = 1.0$ J ✓

(d) TWO differences between progressive and stationary waves. **[02]**

- In a progressive wave (e.g. sound from the speaker toward Ocen's car), energy is transferred in the direction of wave travel. In a stationary wave (e.g. Kizza's endingidi string), energy is not transferred; it is stored in the vibrating medium between the nodes.
- In a progressive wave, all particles have the same amplitude (in an ideal medium). In a stationary wave, particles at antinodes have maximum amplitude and particles at nodes have zero amplitude.

OR

ITEM 6 — Suggested Solutions **Total: 20 marks**

(a) Angle of refraction, critical angle, optical fibre diagram and explanation. **[08]**

(i) Snell's law: $n_1 \sin\theta_1 = n_2 \sin\theta_2$

$1.0 \times \sin 40° = 1.52 \times \sin\theta_2 \rightarrow \sin\theta_2 = 0.6428 / 1.52 = 0.4229$ [M1]

$\therefore \theta_2 = 25.0°$ ✓

(ii) Critical angle: $\sin C = 1/n = 1/1.52 = 0.6579$ [M1]

$\therefore C = 41.1°$ ✓

(iii) Optical fibre diagram requirements (award [B1] for labelled diagram):

- Core (high refractive index $n_1 = 1.52$) surrounded by cladding (lower refractive index $n_2 < n_1$).
- Light ray shown entering the core at the input end, striking the core-cladding boundary at an angle greater than the critical angle (≈ 41.1°), and undergoing total internal reflection repeatedly along the length of the fibre.
- Explanation: because the angle of incidence at every reflection exceeds the critical angle, no light refracts out through the cladding — 100% of the ray is reflected back into the core. The pulse travels from Kampala to Gulu by thousands of successive total internal reflections, losing negligible energy through the walls.

(b) P-V diagram, work done in isothermal expansion, first law for isochoric steps. **[08]**

(i) P-V diagram features (award [B1] for correct shape, [B1] for labels):

- Step 1: isothermal expansion at 500 K — hyperbolic curve from (2.0 L, 3.0×10^5 Pa) to (6.0 L, $\sim1.0\times10^5$ Pa). Upper curve.
- Step 2: constant-volume cooling at V = 6.0 L — vertical line downward from 500 K isotherm to 300 K isotherm.
- Step 3: isothermal compression at 300 K — hyperbolic curve from (6.0 L) back to (2.0 L). Lower curve.
- Step 4: constant-volume heating at V = 2.0 L — vertical line upward back to start. Cycle closed.

(ii) Work done in isothermal expansion:

$W = P_1V_1 \ln(V_2/V_1) = nRT \ln(V_2/V_1)$ [M1]

$P_1V_1 = 3.0\times10^5 \times 2.0\times10^{-3} = 600$ J; $V_2/V_1 = 6.0/2.0 = 3$ [M1]

$W = 600 \times \ln 3 = 600 \times 1.099$ **[A1]**

$\therefore$ $W = 659$ J ≈ 660 J (work done BY the gas) ✓

(iii) First law: $\Delta U = Q - W$ **[B1]**

Step 2 — isochoric cooling (V constant → W = 0): $\Delta U = Q$ **[M1]**

- Temperature drops 500 K → 300 K, so internal energy decreases ($\Delta U < 0$).

$\therefore$ $Q_2 = \Delta U < 0$ → heat is RELEASED by the gas to the surroundings during cooling. ✓

Step 4 — isochoric heating (V constant → W = 0): $\Delta U = Q$

- Temperature rises 300 K → 500 K, so internal energy increases ($\Delta U > 0$).

$\therefore$ $Q_4 = \Delta U > 0$ → heat is ABSORBED by the gas from the surroundings during heating. ✓

(c) Calorimetry: does all ice melt? Final temperature. **[04]**

Heat available if water + calorimeter cool from 20°C to 0°C:

$Q_{avail} = (m_{Cu}c_{Cu} + m_w c_w) \times \Delta T = (0.100\times400 + 0.200\times4200) \times 20$ **[M1]**

$= (40 + 840) \times 20 = 880 \times 20 = 17\,600$ J

Heat required to melt all ice:

$Q_{melt} = m_{ice} \times L_f = 0.050 \times 3.36\times10^5 = 16\,800$ J **[M1]**

$\therefore$ $Q_{avail} = 17\,600$ J $> Q_{melt} = 16\,800$ J → ALL the ice melts. ✓ ✓

Final temperature — heat balance (let T_f be final temperature above 0°C):

Heat lost by water + calorimeter = Heat gained by ice (melting + warming) **[M1]**

$(0.100\times400 + 0.200\times4200)(20 - T_f) = 16\,800 + 0.050\times4200\times T_f$

$880(20 - T_f) = 16\,800 + 210T_f$

$17\,600 - 880T_f = 16\,800 + 210T_f$

$800 = 1090\,T_f$

$\therefore$ $T_f = 800 / 1090 = 0.73$ °C ✓

SECTION D: CHARGES AND FIELDS — MARKING SCHEME

ITEM 7 — Suggested Solutions Total: 20 marks

(a) Transformer turns, primary current, energy losses and minimisation. **[08]**

(i) Turns ratio:

$N_s / N_p = V_s / V_p \rightarrow N_s = 2000 \times (12/240) = 2000 \times 0.05$ **[M1]**

$\therefore N_s = 100$ turns ✓

(ii) Primary current (100% efficiency → $P_{in} = P_{out}$):

$V_p I_p = V_s I_s \rightarrow I_p = (12 \times 1.5) / 240 = 18 / 240$ **[M1]**

$\therefore I_p = 0.075$ A ✓

(iii) Energy loss sources (award [1] per cause + [1] per correct minimisation, max [4]):

- Eddy current losses: induced circulating currents in the iron core dissipate energy as heat (Joule heating). **Minimised** by using a laminated core — thin insulated iron sheets reduce the area available for eddy currents, reducing I^2R losses.
- Resistive (copper/I^2R) losses: current flowing through the resistance of the copper windings generates heat. **Minimised** by using thick, low-resistance copper wire for the windings.
- Hysteresis losses: energy is lost each cycle as the magnetic domains in the iron core are repeatedly realigned. **Minimised** by using soft iron (magnetically 'soft' material with a narrow hysteresis loop) for the core.

(b) AC generator: peak EMF expression, rms EMF, rms current. **[06]**

(i) Instantaneous EMF: $\varepsilon(t) = NBA\omega \sin(\omega t)$

Peak EMF: $\varepsilon_0 = NBA\omega = 50 \times 0.30 \times 0.020 \times 100\pi$ **[M1]**

$= 50 \times 0.30 \times 0.020 \times 314.16 = 50 \times 1.8850$ **[A1]**

$\therefore \varepsilon_0 = 94.25 \text{ V} \approx 94.2 \text{ V}$ ✓

(ii) rms EMF:

$\varepsilon_{rms} = \varepsilon_0 / \sqrt{2} = 94.25 / 1.4142$ **[M1]**

$\therefore \varepsilon_{rms} = 66.7$ V ✓

(iii) rms current:

$I_{rms} = \varepsilon_{rms} / R = 66.7 / 40$ **[M1]**

$\therefore I_{rms} = 1.67$ A ✓

(c) Force on conductor; galvanometer principle and adaptations. **[06]**

(i) Force on conductor:

$F = BIl = 0.30 \times 4.0 \times 0.50$ **[M1]**

$\therefore F = 0.60$ N ✓

(ii) Moving-coil galvanometer principle:

- A rectangular coil of many turns is suspended between the poles of a permanent magnet in a radial field. When a current I flows through the coil, it experiences a torque $\tau = NBIA$, where N = turns, B = field, I = current, A = coil area.
- This deflecting torque is balanced by a restoring torque from a hairspring: $\tau = k\theta$, where k is the spring constant and θ is the deflection angle. At equilibrium: $NBIA = k\theta \rightarrow \theta \propto I$. The pointer deflection is directly proportional to the current.

- As an AMMETER: a small resistance called a shunt (S) is connected in PARALLEL with the galvanometer. Most of the large current flows through the shunt; only a small fraction passes through the galvanometer coil. $S = I_gG / (I - I_g)$, where G is coil resistance.
- As a VOLTMETER: a large resistance called a multiplier (M) is connected in SERIES with the galvanometer. This limits the current through the coil to a safe value even when measuring large voltages. $M = (V/I_g) - G$.

📌 **Note:** *Award [1] for diagram of ammeter adaptation, [1] for diagram of voltmeter adaptation, [1] for principle.*

OR

ITEM 8 — Suggested Solutions — Total: 20 marks

(a) Coulomb force, zero-field position, electric potential at midpoint. **[08]**

(i) Electrostatic force:

$F = kQ_1Q_2/r^2 = 9.0\times10^9 \times (6\times10^{-6}) \times (4\times10^{-6}) / (0.30)^2$ **[M1]**

$= 9.0\times10^9 \times 24\times10^{-12} / 0.09 = 216\times10^{-3} / 0.09$

$\therefore F = 2.4$ N (ATTRACTIVE — charges are of opposite sign) ✓

(ii) Zero electric field position:

Between the charges, both fields point in the SAME direction (from + toward −) — they cannot cancel. Zero field must be OUTSIDE, beyond the smaller charge $Q_2 = -4\mu C$. **[M1]**

Let d = distance from Q_1 to the zero-field point (beyond Q_2, so $d > 0.30$ m):

$kQ_1/d^2 = kQ_2/(d - 0.30)^2 \rightarrow 6/d^2 = 4/(d - 0.30)^2$ **[M1]**

$6(d - 0.30)^2 = 4d^2 \rightarrow 6d^2 - 3.6d + 0.54 = 4d^2$

$2d^2 - 3.6d + 0.54 = 0 \rightarrow d^2 - 1.8d + 0.27 = 0$

$d = [1.8 \pm \sqrt{(3.24 - 1.08)}] / 2 = [1.8 \pm \sqrt{2.16}] / 2 = [1.8 \pm 1.470] / 2$ **[A1]**

$\therefore d = 1.635$ m from Q_1 (i.e. 1.335 m beyond Q_2, on the far side from Q_1) ✓

📌 **Note:** *Reject the root d = 0.165 m as it lies between the charges where fields cannot cancel.*

(iii) Electric potential at midpoint ($r_1 = r_2 = 0.15$ m):

$V = k(Q_1/r_1 + Q_2/r_2) = 9.0\times10^9 \times [(+6\times10^{-6}) + (-4\times10^{-6})] / 0.15$ **[M1]**

$= 9.0\times10^9 \times 2\times10^{-6} / 0.15 = 18\times10^3 / 0.15$ **[A1]**

$\therefore V = 1.20 \times 10^5$ V $= 120\,000$ V ✓

(b) Capacitor bank: series and parallel capacitance, energy, application. **[06]**

(i) Series configuration:

$1/C = 1/4 + 1/6 + 1/12 = 3/12 + 2/12 + 1/12 = 6/12 = 1/2$ **[M1]**

$\therefore C_{series} = 2\ \mu F$ ✓

$E = ½CV^2 = ½ \times 2\times10^{-6} \times (24)^2 = ½ \times 2\times10^{-6} \times 576$ **[M1]**

$\therefore E_{series} = 5.76 \times 10^{-4}\ J = 0.576\ mJ$ ✓

(ii) Parallel configuration:

$C = 4 + 6 + 12$ **[M1]**

$\therefore C_{parallel} = 22\ \mu F$ ✓

$E = ½ \times 22\times10^{-6} \times 576$ **[M1]**

$\therefore E_{parallel} = 6.336 \times 10^{-3}\ J = 6.34\ mJ$ ✓

Application (award [1]):

- In a UPS power supply (as found in the workshop), capacitors are used to smooth the rectified DC output — they charge during voltage peaks and discharge during troughs, reducing ripple voltage and delivering stable DC to electronic components.

(c) Circuit diagram, total resistance, battery current, terminal voltage, power. **[06]**

(i) Circuit diagram: 6 Ω // 12 Ω in parallel, combined in series with 4 Ω, connected to 12 V cell of internal resistance 1 Ω. Award [B1] for correct, clearly labelled diagram. **[B1]**

(ii) Parallel combination of 6 Ω and 12 Ω:

$1/R_{//} = 1/6 + 1/12 = 2/12 + 1/12 = 3/12 = 1/4 \rightarrow R_{//} = 4\ \Omega$ **[M1]**

Total external resistance: $R_{ext} = R_{//} + 4 = 4 + 4 = 8\ \Omega$ **[A1]**

$\therefore$ Total external resistance $= 8\ \Omega$ ✓

(iii) Battery current:

$I = EMF / (R_{ext} + r) = 12 / (8 + 1) = 12 / 9$ **[M1]**

$\therefore I = 1.33\ A$ ✓

(iv) Terminal voltage:

$V_T = EMF - Ir = 12 - 1.33 \times 1$ **[M1]**

$\therefore V_T = 10.67\ V \approx 10.7\ V$ ✓

(v) Power in 4 Ω series resistor:

$P = I^2R = (1.33)^2 \times 4 = 1.777 \times 4$ **[M1]**

$\therefore P = 7.11\ W \approx 7.1\ W$ ✓

END OF MARKING SCHEME